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An Agent-based Model for Flexible Customization in Product-Service Systems

Maryam Farsi[a]*, John Ahmet Erkoyuncu[a]

[a] *Through-life Engineering Services Centre, Cranfield University, Cranfield, MK43 0AL, UK*

* Corresponding author. Tel.: +44-123-475-0111; *E-mail address:* maryam.farsi@cranfield.ac.uk

Abstract

Product-Service System (PSS) models offer an integrated service solution to create value for businesses. In the high-value manufacturing sector, value creation for maintaining market competitiveness and improving customer satisfaction is a challenging task. Designing an effective PSS solution depends on integrated service, and product requirements and constraints. Thereby, PSS contract decisions can be significantly influenced by customers' requirements, and also product and service features. However, existing literature primarily focuses on the impact of service requirements on the PSS contract decisions. Moreover, the existing insights for PSS customization mainly consider hysteretic customer requirements rather than forecasting the requirements under product and service uncertainties. In this paper, an agent-based cost-benefit analysis simulation model is implemented for the PSS contract decisions context. Moreover, a sensitivity analysis is conducted on service costs. Additionally, the effect of product remaining life on service contract decisions is analyzed. The simulation model considers stochastic uncertainty to study PSS contracts customization. The presented model supports PSS customization process by providing a quantitative tool that measures contracts' profitability as early as the requirement elicitation phase. Furthermore, the bottom-up nature of the model, and the integration of probabilistic uncertainties enhance the flexibility of PSS customization. A case study of PSS contract decision in the machine tool industry is considered for assessing the validity of the presented model. Studies on different forms of service uncertainty highlight that the product failure rate has the most influence on the profitability of a service contract. Moreover, the impact of product age on profitability in an availability-based contract is more significant compared to a spare-parts contract.

Keywords: Product-Service System; Servitization; Uncertainty; Sensitivity Analysis; Agent-based Modeling; Flexible Customization

1. Introduction

Flexible customization in Product-Service Systems (PSS), provides an opportunity for manufacturers and service providers to enhance their competitiveness and satisfy their diverse customers' demands. In high-value manufacturing industries, flexible customization is more crucial for service contracts profitability. In such sectors, fulfilling customers' requirements is even more challenging considering the inherent complexities of PSS contracts. Such complexities mainly arise from health and condition monitoring of high-value assets. Therefore, the high level of uncertainty in maintenance and repair planning activities over the service contract complicates profit determinability. In this regard, flexible customization can provide more insights and assurances for manufacturers and providers, when designing PSS contracts based on their customers' requirements. The term PSS has been defined as "a marketable set of products and services capable of jointly fulfilling a user's need. The product/service ratio in this set can vary, either in terms of function fulfilment or economic value" [1,2]. The shift from product/service-based business model strategies toward a customer-oriented mindset is termed as 'servitization of business' by Vandermerwe and Rada [3]. Servitization can be described as the movement of businesses

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from products-oriented to solution-oriented; from asset ownership to asset utilization; and from mass production to mass customization [4,5]. In manufacturing, flexible customization provides customers with a wide range of options rather than a single specification to choose from [6]. Flexible customization also embraces flexibility in production planning, market demands, customer requirements, manufacturing processes and capacity, and flexible production of customized orders [7]. PSS customization has been studied by many authors in the past two decades, mostly in production, construction and software development sectors. Several works have studied the concept by following qualitative and interpretive approaches. Although mass customization and PSS have been implemented in many industrial sectors, customization of integrated product and service offerings, and uncertainty considerations are still underexplored.

In this paper, a Cost-Benefit Analysis (CBA) simulation model for PSS decisions based on a bottom-up lifecycle costing approach is presented. The model performs sensitivity analysis for service costs, service cycle-times and their occurrences. Additionally, the effect of product remaining life on different service contract decisions are analyzed. The dynamic simulation model considers stochastic uncertainty to study flexible customization of PSS contracts. In this study, the authors address the following research question: "How flexible customization can influence the profitability of PSS service contracts?". Thereby, this piece of research extends the knowledge in the area of 'flexible customization' and presents a decision-making support model for flexible customization in PSS contracts. In the presented model, flexibility is fulfilled by providing several service support options when presenting the PSS contract to customers. The list of options includes product and service requirements, product's ownership, and end-of-contract scenarios. Moreover, for the service provider, the flexibility is offered by providing a holistic view on different service options, and value creation throughout the entire product lifecycle. This research work focuses on two types of service contracts: spare-parts and availability-based, with a view to demonstrate the applicability of the proposed model for flexible customization in PSS.

This paper is structured as follows: Section 2 reviews the key literature on mass customization and PSS. The proposed agent-based model for PSS customization is presented in Section 3. Section 4 outlines the adopted case study for developing the PSS customization model. Section 5 provides a discussion on the model implementation. The paper is concluded in Section 6.

2. State of the Art

Since the early 19th century, customization as a concept has been adopted by manufacturers in different sectors resulting in mass customization. It allows businesses to manufacture custom-made products efficiently. However, the employment of customization concept in the service domain and PSS is limited to the past two decades. Sundin *et al.* [8] demonstrated how mass customization could enable manufacturers to expand their service options for their customized products through the 'servicification' concept. The potential effect of service customization on customer loyalty is highlighted by Coelho and Henseler [9]. They proposed a model that associates customer relationship outcomes with customization efficiency. Their findings confirmed the positive effect of customization on service quality, customer satisfaction, trust, and ultimately customer loyalty. Chen *et al.* [10] conducted a review study focusing on the concepts of service delivery and mass customization to assess the role of customization in PSS design. They presented a set of suggestions for mass customization in the service delivery system design.

The concept of flexibility in PSS customization is widely intertwined with the two concepts of 'modularisation' and 'personalization' within the literature. Flexible customization is mainly described as the flexibility in modular production, personalized product design, and flexibility in service planning for customized products. For instance, Bask *et al.* [11] introduced a framework for modularity and customization of services in order to support manufacturers in qualitatively analyzing and comparing service offerings. Moreover, Geum *et al.* [12] proposed a customization framework that highlights technological requirements for PSS implementation and road-mapping. A PSS customization method was proposed by Kim *et al.* [13] to offer effective customization through context-based activity modelling for different stakeholders. Zine *et al.* [14] expanded the concept of PSS customization and proposed a framework for value co-creation for manufacturers and their customers. They concluded that the co-design of products and services, and co-production could increase productivity.

In a recent study, a value co-creation design method for PSS is proposed by Rizvi et al. [15], that combines the concepts of actor-network theory and service-dominant logic. Their method aimed to identify the actors (i.e. stakeholders), practices and possibilities throughout the design process. A modularisation method focused on functional requirements in PSS customization is presented by Sun *et al.* [16]. Utilizing the fuzzy clustering approach, the authors presented a set of potential modules for PSS, based on product specifications and service activities. A view-based model-driven engineering approach was proposed by Elgammal *et al.* [17] for PSS customization design. Their approach allows a systematic transformation of an abstract PSS model into a tailor-made one.

Furthermore, Mourtzis *et al.* [18] proposed a framework for PSS customization, presenting the main steps which are required for a successful PSS delivery. The recommended steps include: market research, value chain assessment, technology identification, customizability measurement, and finally, dynamic feedback collection. Later, they expanded the PSS customization paradigm and proposed a methodology to quantify the complexity of PSS customization. Their method supports manufacturers when selecting customized products and services that are offered to their customers [19]. Moreover, Sousa and *da* Silveira [20] presented the relationship between product customization and servitization strategies. They focused on the interlink between the strategy intensity and the degree of service offerings. The outcome from their qualitative approach indicated that the intensity of customization strategy is positively associated with the level of service offering.

In a recent study, Fargnoli *et al*. [21] expanded the works of [13,17,19,22] and proposed a PSS modularisation methodology to support manufacturers in designing services that fulfil customers' needs and expectations. Their method highlighted a correlation between customers' expectations and PSS components. Their method deploys a quality function for PSS, axiomatic design and the service blueprint tools. Currently, there is an emphasis on the role of mass customization in product and service innovation capabilities [23]. In this regard, Pallant and Sands [24] proposed four strategies for mass customization: co-production, co-construction, co-design, and co-configuration to enhance the integrity and flexibility of PSS customization.

2.1. Research gap

Overall, the existing literature on flexible customization in PSS are sparse and limited to qualitative approaches; these approaches have mostly had a focus on the flexibility in production and service planning and the impact of service requirements on PSS contract decisions. Moreover, the existing findings for PSS customization are based on hysteretic customer requirements rather than forecasting the requirements under product and service uncertainties. Nevertheless, there is a lack of research evidence on quantitative methods to assess the profitability of PSS contracts under uncertainty when providing flexible customization for integrated product and service requirements. Hence, this research work aims to present an agent-based simulation model for PSS contract decisions to enhance flexible customization in two types of spare-parts and availability-based contacts.

3. Agent-based Model of Flexible Customization for PSS

A PSS customization paradigm allows businesses to improve their service offering portfolio by also providing personalized products and services. Moreover, flexible customization enables businesses to have more control over customer requirements, which can consequently allow them to assess and gauge profitability. However, flexibility for PSS customization poses new challenges e.g. the requirement for further data gathering and analytics in relation to product and service performances. Business process simulation for PSS design has been conducted by researchers using approaches such as discrete-event simulation, system dynamics, and agent-based modelling. In this paper, an agent-based model for PSS decisions is implemented to conduct cost-benefit analysis (CBA) in a PSS contractual agreement. The model aims to estimate the costs/benefits through the length of a PSS contract from product acquirement to the end-of-contract. To construct the agent-based model, a '*Main agent*' is created to facilitate CBA in a PSS contract. The model time unit is set as 'day'. Within the agent, a state-chart with different '*states'* is designed. The states represent various cost events throughout the PSS contract.

These events and the critical cost drivers (i.e. cost activities) are summarized in Table 1.

Table 1: List of 'states' in the presented agent-based model[1]

Cost events (states)	Cost/benefit drivers	Cost events (states)	Cost/benefit drivers
Acquire	Purchase, rent/lease, legal fee, disassembly, transport	BM (MPEOM[2])	Baseline installed maintenance and monitoring
Install	Assembly, testing, specification, installation, integration	Disassembly	Remove, disassembly, inspection
Operate	Consumables, Labour operator, training	CM - Replace	Unscheduled replacement
Standby support	Standby support	CM - Repair	Unscheduled repair
Consultation	Consultation	Reject	Reject
Upgrades	Machine and part upgrades, part disposal	Other *(not as a separate state)*	Penalty/ incentive
CBM	Sensors purchase/installation, IT, CBM	Uninstall	Uninstallation, disassembly, transport
PM - Repair	Scheduled repair	Reassembly	Reassembly
PM - Replace	Scheduled replacement	End-of Contract	Retrofit, resale

Different states are connected to each other using '*Timeout transitions*' within the agent-based model. The simulation model is built in AnyLogic 8 University version, which is illustrated in Fig. 1. The timeout is defined as the cycle-time, which is required to complete each cost event. Moreover, to calculate the cost in '*Action*' of each state, C_s, the activity-based costing approach is formulated as:

$$C_s = \sum UC_s \times CT_s, \quad (1)$$

where, UC_s is the unit cost (i.e. cost of the event per unit time) and CT_s is the cycle-time of each event. The total lifecycle cost (LCC) is ultimately calculated in a '*function*' as:

$$LCC = \sum C_s, \quad (2)$$

The benefit includes the revenue from selling a product and offering a service, and it is calculated based on the rate of return for purchases and services (see Table 3).

To fulfil flexible customization, the simulation model provides an optional list of choices for customers and service providers which includes product and service requirements, product's ownership, buying/selling scenarios, end-of-contract scenarios, service planning, and value creation at the end of the contract. Flexible customization is simulated using the following parameters and variables as summarized in Table 2.

Table 2: Case-study - Flexible customization in PSS.

Input Parameter/Variable	Input Type	Flexibility option
OEM existing product/ Retrofit product	Integer Boolean	Product buying options for provider
Repair & maintenance rate/ Consultancy/ Standby monitoring & support	Double	Service planning
Agreed availability	Percentage	Level of required availability for the product
Inservice/ penalty	Percentage	The amount of incentive and penalty due to the lack of agreed performance
Selling/ Renting/ Leasing	Integer Boolean	Selling options for providers and customers
Product remaining life	Double	Failure rate will be adapted based on the remaining useful life of components
Remove/ Retrofit/ Re-sell	Integer Boolean	End-of-contract options for providers and customers

[1] CBM: Condition-Based Maintenance; PM: Preventive Maintenance; CM: Corrective Maintenance, BM: Base Maintenance

[2] Machine Performance Evaluate Optimise Monitor

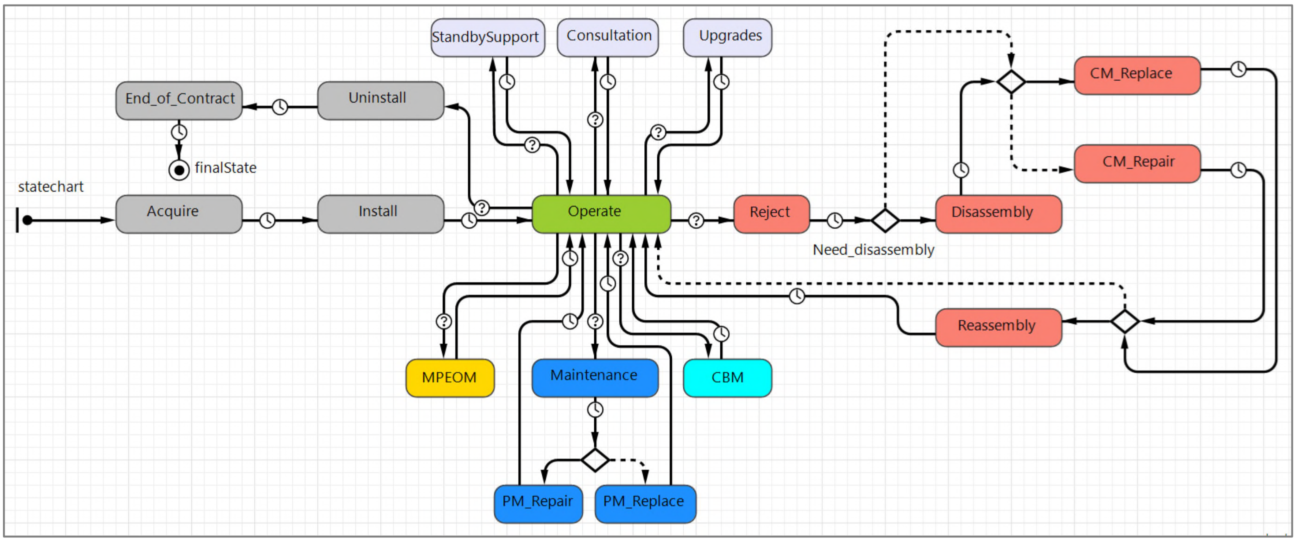

Fig. 1: Agent-based state diagram of the cost-benefit model for PSS in AnyLogic software.

4. Case Study and Results

To demonstrate the validity of the proposed agent-based model in PSS flexible customization, a case study of a bespoke service provider in the UK is adopted. The service provider offers tailored services for machine tools. In this study, the servitization of a CNC machine is considered. Several workshops and interviews were conducted with the experts in the company to collect the product and service data required to develop the simulation model. Probabilistic uncertainty is examined in service costs and their occurrences, and the simulation input is summarized in Table 3. Two main scenarios for PSS contracts have been modelled, (1) a product-oriented PSS spare-parts contract, and (2) a use-oriented PSS availability-based contract. In scenario 1, the provider buys a machine from an OEM and sells to its customer. Note that the provider may require retrofitting the machine before selling it. In this scenario, the provider is responsible for Base Maintenance (BM), Corrective Maintenance (CM), and provision of standby support and consultation on request. In scenario 2, the provider acquires the machine and rents/leases it to the customer. The provider is still responsible for all the maintenance and repair i.e. Corrective, Preventive, and Condition-Based Maintenance (CBM) to satisfy the agreed level of product availability. The provider may need to pay penalties or may receive incentives depending on product availability. In the first scenario, the ownership of the machine will stay with the customer and therefore, there are no cost/benefit drivers at the end of the contract. Whereas, in the second scenario, the provider can retain the ownership and will have the option to retrofit (e.g. re-manufacture, re-purpose, re-use) or re-sell the machine. In this case, the fixed rate of depreciation was considered as 17% per year.

Table 3: Agent-based simulation input for the case study; T (triangular), U (uniform), y (year), m (month), w (week), d (day), e (event).

Input Parameter/Variable	Unit Cost (£K)	Cycle-time (Day)	Frequency (/year)
Purchase price	348.00	-	One-off
Renting/leasing	10.00 /m	-	12
Other ‘acquire’ cost	5.60	-	One-off
Install	52.8 /w	T (1, 2, 4) w	One-off
Cost of spares	T (5, 15, 30) /y	-	50% of CMs and PMs
Operate cost	0.9 /d	U (1, 2) d	One-off
Standby	0.5 /m	-	12
Consultation	1.5 /e	-	2
BM	3.75 /d	U (5, 10) d	1
PM	0.475 /d	U (1, 2) +1 d	2
CM	0.475 /d	T (1, 2.5, 4) +1 d	U (5, 10)
CBM	0.475 /d	U (2, 5) d	2
Penalty/ Incentive	0.1 / 1% un/availability	-	-
Sensors	22.5 /y	-	1
IT	0.4 /m	-	12
Part Dis(re)-assemblies	0.475 /e	5 ± 0.05 d	-
Uninstall	1.5 /d	T (5,7,10) d	One-off
Retrofit	50.00	-	One-off
Rate of return on purchases and Investments			20% - 30%
Rate of return on service			90% - 110%
Failure rate		Age ≤ 1 Year Age >1 and ≤ 5 Age >5 and ≤ 10 Age > 10	U (5,10) U (1, 5) U (1, 5) U (5,10)

The probabilistic uncertainty is measured for service costs, cycle-times and the occurrences as presented in Table 3. The two PSS scenarios are represented using the agent-based model. The sensitivity analysis of the total cost of the PSS contract in scenario-1 and scenario-2 are conducted. By assuming the length of the contract as 15 years, the effect of the machine remaining life on PSS contract cost and benefit (i.e. contract price) are examined and presented as best-fit trendline curves of the probability distribution for each age category with average R-values, in Fig. 2 for Scenario-1 and in Fig. 3 for Scenario-2.

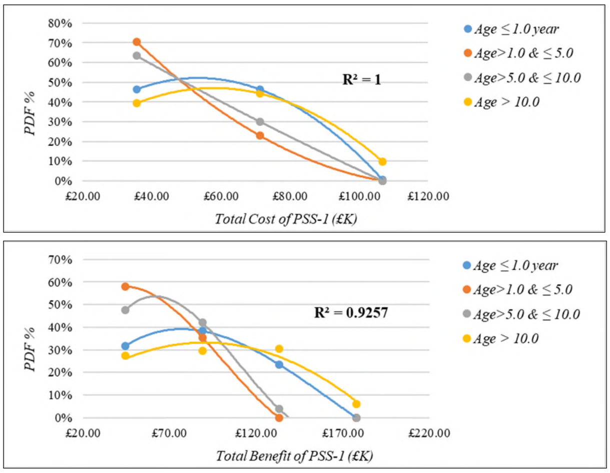

Fig. 2: Effect of product remaining life on the contract price in Scenario 1.

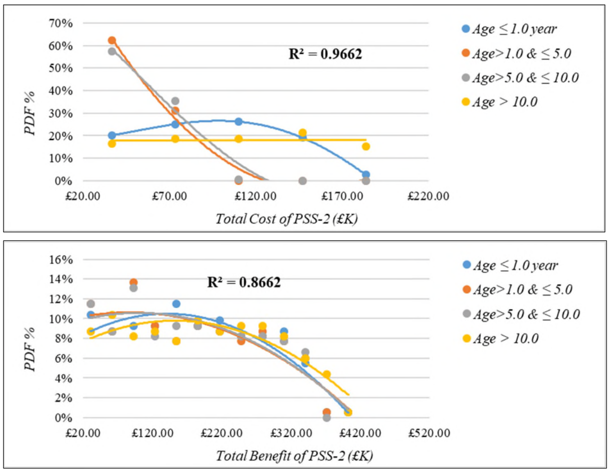

Fig. 3: Effect of product remaining life on the contract price in Scenario 2.

The radar chart in Fig. 4 shows the normalized impact of remaining life on the profitability of the PSS contract. The numbers around the chart represent the age of the product, and the percentages are the average profitability over the 15-year contract. The results show that in Scenario-1, the spare-part contracts are more profitable when the product is older than ten years. In contrast, the availability-based contract in Scenario-2 is more profitable when the product is relatively new. Overall, the availability-based contract is more profitable compared to the spare-part contract over a 15-year contract.

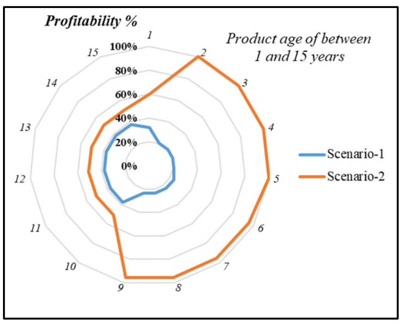

Fig. 4: Average profitability of PSS contract for Scenario-1 and 2

Further analysis is carried out in scenario-2 to highlight which input has the most influence on the service cost. Since the service unit costs will have a clear linear impact, the scheduled maintenance frequency and failure rate have been selected for this analysis. The scatter plot with a linear fit line in Fig. 5 represents the impact of the frequency on the PSS contract profitability in Scenario-2.

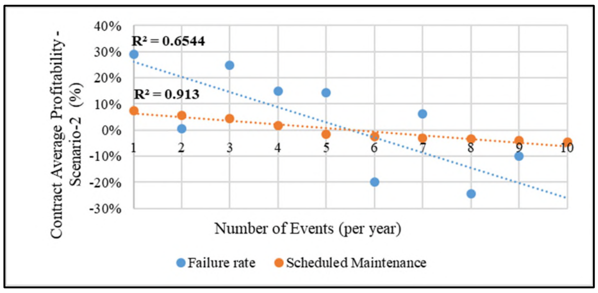

Fig. 5: Effect of service requirements on PSS profitability Scenario-2.

The average number of events for scheduled maintenance and the product's failure over the 15-year period is considered based on the figures in Table 3. The effect of scheduled maintenance events on profitability is averaged among the frequency of BM, PM and CBM services per their unit time. Moreover, the effect of the failure rate on profitability is averaged among different age categories based on figures in Table 3. The latter shows a relatively high uncertainty in profitability.

5. Discussion

The presented PSS customization model highlights the effect of flexibility in the integrated product and service requirements. The sensitivity analysis results related to the product remaining life show that the impact of product age on profitability in availability-based contracts (Scenario-2) is more significant compared to spare part contracts (Scenario-1). Moreover, we have analyzed stochastic uncertainty in service cost, by presenting trendline curves of the probability distribution of the PSS cost and benefit for different product ages. The results highlight that the uncertainty in the cost estimates of a PSS contract for new products or products close to their end-of-life compared to the cost-estimates for middle-age products is higher (see Fig. 2 and Fig. 3). Moreover, the overall uncertainty in benefit estimates in Scenario 2 is higher than in Scenario 1. Furthermore, in a 15 years contract, the availability-based contract is more profitable compared to the spare-part contract (see Fig. 4). Since the frequency of services positively relates to the age of products, the sensitivity of maintenance and repair frequencies are studied for the second scenario. The results for the case study show that failure rate has a more significant influence on the profitability of a contract, compared to number of scheduled maintenance. Moreover, when the frequencies of such disruptions become more than a certain amount i.e. scheduled more than 5 per year and unscheduled more than 6 per year, the contract is no longer profitable (see Fig. 5).

6. Conclusion

In this paper, a cost-benefit analysis simulation model for PSS design is presented. The simulation model is developed in AnyLogic software using the agent-based technique to present a bottom-up activity-based costing approach to estimate PSS profitability. A case study of PSS contract decision in the machine tool industry is considered for assessing the validity of the presented model. In this regard, a series of sensitivity analyses related to service costs, service cycle-times and their occurrences are implemented. Moreover, the effect of changing product remaining life on the service contract price is investigated. The bottom-up nature of the model, together with the integration of probabilistic uncertainties on model input, enhances the flexibility of PSS customization. Two scenarios for PSS contracts are considered: spare-part and availability-based contracts. The presented model supports a flexible PSS customization process by providing a quantitative tool that measures the contract profitability as early as the requirement elicitation phase. Based on the analysis carried out on the case study, the following conclusions are drawn:

- The uncertainty in the cost and benefit estimates of PSS contracts for middle-age products (age >1 and ≤10) are relatively low.
- In a 15-year contract, the availability-based contract is more profitable compared to the spare-part contract.
- The PSS contract profitability is highly sensitive to the product failure rate.

Integration of the Industry 4.0 principles with PSS customization concepts can further enhance the flexibility of the presented approach. Future work will be required to focus on improving adaptability in service contracts against market demand by implementing I4.0.

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Farsi, Maryam

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